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ECONOMIC LOAD DISPATCH OF THERMAL GENERATION – A COMPARISON OF GRG ALGORITHM WITH EVOLUTIONARY ALGORITHM IN SOLVER

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ABSTRACT

In this paper, the problem of load dispatch of Thermal power generation considering all the various system constraints is discussed using generalized reduced gradient (GRG) algorithm and Evolutionary algorithm nonlinear optimization and the results are compared. The most economical operating costs can be obtained by distributing the load demand to the interconnected generators i.e., Load dispatch, while considering their various constraints. The operation of Thermal Power plant is very expensive and also each generating unit usually has a unique cost-per-hour characteristics, minimum and maximum operating powers, ramp rates, prohibited operating zones, emission coefficients.

In this paper, ELD is calculated for IEEE-30 bus system connected to six thermal power plants. Here transmission line losses are also taken into consideration. ELD is calculated using GRG algorithm and Evolutionary algorithm and the results are compared. These algorithms present in Solver tool of Excel add-in program are applicable to arrive at an optimum value (maximum or minimum value) in an objective cell within predetermined constraints or limits. The results on optimizations have shown that the GRG algorithm is better compared to Evolutionary algorithm in solver in a given time, as the evolutionary algorithm takes more time to converge and more number of iterations to arrive at the conclusions to find a feasible solution.

KEYWORDS: Load Dispatch, Fuel Cost, Émissions, Prohibited Operating Zones, Ramp Rate Limits Transmission Losses & Evolutionary Algorithms

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Original Article

1. INTRODUCTION

The rapid increase in Electrical Load demand due to development in technology and its usability throughout the globe has given rise to many ideas of producing power. Interconnecting a number of generators and to operate them economically to the requirements of the ever changing load demand has become a very difficult and an important task. A number of generating units are connected in parallel to a common bus bar and are synchronized to ensure the safe and reliable supply of a large amount of the connected load, The main purpose of Economic Load dispatch is to supply the load demand while maintaining the fuel cost and operating costs of generating units to the possible minimum levels. Hence an optimized and timely switching of the units must be made possible in order to save the costs to the maximum levels without affecting the load. In this paper, IEEE -30 bus system connected to six thermal generators with their unique cost per hour characteristics, effects due to changes in valve point loading, emissions, transmission line losses and the limits like ramp rate limits for the change in scheduled loads, prohibited operating zones are considered for load demands ranging from 600MW to 1400MW in steps of increase of 200MW and the changes in the cost of load dispatch is analysed.

All the connected generators do not have the same and identical input output characteristic curves, so the load on all the units cannot be symmetrically distributed, as different brands of the generators connected,(which will be the case in genaral) have variable efficiency, have dissimilar input output characteristics and also have different fuel cost curves for different power outputs. It increases the need of ELD to schedule the power of generating units within the acceptable generating limits of each individual generator thereby meeting the output power demand with optimum cost. ELD is to compute the total cost of the power system while fulfilling the load demand through its strategic dispatch.

A number of Modern BIA (Biologically Inspired Algorithms) find their applications to solve ELD. The Evolutionary based algorithms aim at solving problems learning from the collective behaviour in adaptive populations. They utilize the iterative progress considering their growth, development, reproduction, selection, and survival. EAs are the popular classical and established algorithms among nature inspired algorithms, They are based on the biological evolution of nature that is responsible for the design of all living organisms on earth, and their mutual interacting strategies. EAs find solutions to hard problems by employing this powerful design philosophy. EAs are non-deterministic algorithms or cost based optimization algorithms. A family of EAs comprises of genetic algorithm (GA), genetic programming (GP), Differential Evolution, evolutionary strategy (ES) and Paddy Field Algorithm. The members of the family of EA share a number of common features. They are all population-based stochastic search algorithms which perform with best-to-survive criteria. Each algorithm creates an initial population of feasible solutions, and evolves iteratively from generation to generation towards a best solution. As such in successive iterations, fitness-based selection takes place within the population of solutions. The solutions thus obtained are selected for survival into the next round of iterations to arrive at the best solution.

The Ecology based Algorithms are also bio inspired algorithms comprising of the living organisms along with the abiotic environment with which organisms interact such as air, soil, water etc. The family of these include PS2O, Invasive weed colony Algorithm (IWCA), Biogeography based Optimization (BBO). Swarm based Algorithms are also bio inspired and are an extension of EC. While EAs are based on genetic adaptation of organisms, Swarm Intelligence (SI) is based on the collective social behavior of organisms based on their irregular movements in the problem space. SI implements the collective intelligence of groups of simple agents based on the behavior of real-world insect swarms, as a problem-solving tool. The family of SI which can solve ELD problem comprises of Particle swarm optimization (PSO), Ant colony optimization(ACO), Artificial Bee colony optimization(ABC), Fish Swarm Optimization(FSO), Intelligent Water Drops optimization(IWDO), Bat Algorithm(BA), Krill -Herd Algorithm(KHA), Bacterial Foraging Optimization Algorithm(BFOA), Firefly Algorithm (FFA), Artificial Immune system Algorithm(AISA), Group research Algorithm(GRA), Shuffled Frog Leap Algorithm(SFLA) etc.

The Microsoft Office Solver tool present in the additional settings of Excel as Add-ins in Data menu bar uses several algorithms to find optimal solutions like GRG Non-linear, Simplex Linear Programming and Evolutionary engine. It is easy to install run and execute solver in any system having MSOffice and the time taken for execution is also very less compared to various methods of solving ELD. The personal working in Load dispatch centres can work on this for effectively scheduling the load instantly and economically and need not have any programming knowledge. The GRG Nonlinear Solving Method uses the Generalized Reduced Gradient (GRG2) code for solving nonlinear optimization problems. The Simplex Linear Programming Solving Method uses the Simplex and dual Simplex method with bounds on the variables for linear programming problems and use the branch and bound method to solve the problems with integer

constraints. For non-smooth optimization, The Evolutionary Solving Method uses a variety of genetic algorithms and local search methods.

The Generalized Reduced Gradient (GRG) is one of the most popular methods in optimization used to solve nonlinear problems with active inequalities. The variables are separated into a set of basic (dependent) variables and nonbasic (independent) variables. Then, the reduced gradient is computed in order to find the minimum in the search direction. This process is repeated until the convergence is obtained.

The An evolutionary algorithm **applies the principles of evolution found in nature** to the problem of finding an optimal solution. In this algorithm, the decision variables and problem functions are used directly. An evolutionary algorithm for optimization has a different approach from classical methods in terms of randomness, population, mutation, crossover and selection thereby avoiding being trapped at local minima and attaining the most fit solution based on the feasibility.

In this paper the cost of load dispatch on 6 thermal units is calculated for load demands of 600MW, 800MW, 1000MW, 1200MW and 1400MW using GRG algorithm and Evolutionary algorithm in solver add-in of Excel and the results are compared with respect to the speed in execution and economy. Solver an add-in has found its application in what-if analysis and to find an optimal (maximum or minimum) value for a formula in the objective cell in Excel — subjected to constraints, or limits, on the values of other formula cells in any worksheet.

2. METHODOLOGY

Calculating the Economic Load Dispatch of Thermal power plants is to find out the operating cost of power system through the strategic Dispatch (unit commitment) of various generating units connected in parallel while fulfilling load demand taking into account the penalities due to emissions, valve-point loading effects, transmission line losses and also considering the generators minimum and maximum capacities, prohibited operating zones and ramp-rates limits. In general, only real power generated is considered for finding ELD.

2.1 Operating Cost Equation of Thermal Power Plant

The equivalent cost of thermal power generation includes the fixed costs which are independent of the amount of power generated and variable costs which depend on the amount of power generated which inturn depends on the scheduled load. The cost function in quadratic form is given as:

$$Cost_{gen} = \sum_{i=1}^{n} C_i P_i = \sum_{i=1}^{n} a_i P_i^2 + b_i P_i + c_i \tag{1}$$

Where *Ci* is the fuel cost of generating *Pi* amount of output power.

ai, *bi* and *ci* are the fuel cost coefficients for *Pi*.

a_i = coefficient to measure of losses in the ith generator.

b_i = coefficient which represents the fuel cost in the ith generator.

c_i = constant coefficient includes salary, wages, interest and depreciation of the ith generator and is independent of the amount of power generated.

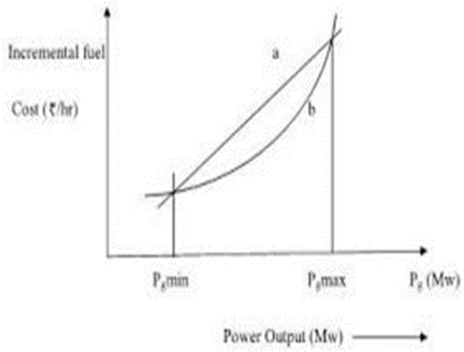


Figure 1: Cost Function Curve of Thermal Power Plant.

2.2 Effects due to Valve Point Loading

Considering the effects due to the changes in valve point loading, which causes rippling effect because of variation in speed of the turbine due to the effect of steam admission through various nozzles, which in turn depends on the power to be generated by a particular unit, $P_{i.}$

$$Cost_{gen} = \sum_{i=1}^{n} C_i P_i = \sum_{i=1}^{n} a_i P_i^2 + b_i P_i + c_i + \left| d_i \sin(e_i (p_i^{min} - p_i)) \right| \quad (2)$$

Where d_i and e_i are the coeffients reflecting valve point loading of ith generator.

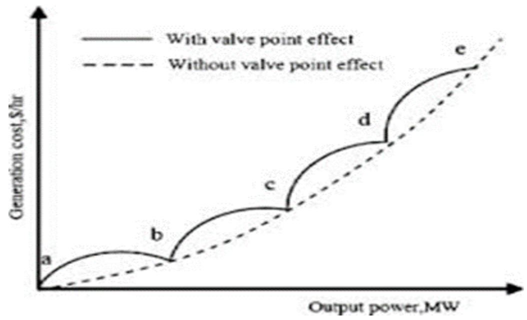


Figure 2: Operating Cost Curve Considering Valve Point Loading Effect.

2.3 Transmission Losses

The losses in the transmission network can be calculated using the formula

$$P_{loss} = \sum_{i}^{n} \sum_{j}^{n} P_i B_{ij} P_j + \sum_{i}^{n} B_{0i} P_i + B_{00} \quad (3)$$

Where B_{ij}, B_{0i}, and B_{00} are the loss coefficient matrices.

1.7	1.2	0.7	-0.1	-0.5	-0.2
1.2	1.4	0.9	0.1	-0.6	-0.1
0.7	0.9	3.1	0	-1	-0.6
-0.1	0.1	0	0.24	-0.6	-0.8
-0.5	-0.6	-0.1	-0.6	12.9	-0.2
0.2	-0.1	-0.6	-0.8	-0.2	15

$B_{ij} = 10^{-5}$ *

0.3908	0.1297	0.747	0.0591	0.2161	0.6635

$B_{oi} = 10^{-5}$ *

$B_{00} = 0.000056$

The total Real power to be generated is the sum of load demand P_D and losses due to transmission, where only real power losses P_{loss} are considered and is given by

$$P_{T\,total} = \sum_{i=1}^{N_g} P_i = P_D + P_{loss} \tag{4}$$

For efficient operation of the units, their power generation must lie within their minimum and maximum capacities.

The inequality constraint considering the generation limits is given by Eq.(5)

$$P_{imin} \leq P_i \leq P_{imax} \tag{5}$$

Where *Pimin* is the minimum generation capacity limit and *Pimax* is the maximum capacity limit of i^{th} generator.

2.4 Cost occurred due to Emissions:

The emissions in the form of COX, SOX and NOX to the atmosphere are subjected to penalty

Further the emissions mostly depend upon the amount of power generated. The load dispatch involves generation of required power for serving the system load with minimum emissions so as to reduce the penalty costs. The emission dispatch function for a particular power generation is given by

$$Emission\ Cost = \sum_{i=1}^{n} \alpha_i\, P_i^2 + \beta_i\, P_i + \gamma_i \tag{8}$$

Where αi, βi, γi are emission coefficients of the ith generating unit

The Objective function considering valve point loading and emission is given as

$$\text{Min}(Cost_{gen}) = Min\,(\sum_{i=1}^{n}((a_i\, P_i^2 + b_i\, P_i + c_i + \left| d_i \sin(e_i\,(p_i^{min} - p_i)\right| + h_i\big(\alpha_i P_i^2 + \beta_i\, P_i + \gamma_i\big))) \tag{9}$$

$$\text{Where } h_i = \frac{a_i\, P_{imax}^2 + b_i\, P_{i\,max} + c_i}{\alpha_i P_{imax}^2 + \beta_i\, P_{imax} + \gamma_i} \tag{10}$$

Where P_{imax} is the maximum capacity of generation i^{th} generator

h_i is the price penalty factor of emissions for i^{th} generator.

h_i for a particular load demand is obtained by calculating the value of h_i for each generating unit, arranging these values $of\ h_i$ in assending order along with the corresponding P_{max} of the units and finding the cumulative values of maximum power generation. The value of h_i for a particular load demand is the value of h_i corresponding to the cumulative $P_{max.}$

2.5 Ramp Rate Limits

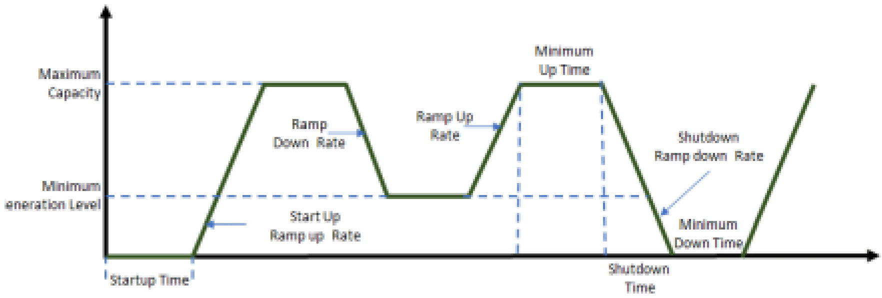
For balancing the net load, providing flexibility and reliability of operation, the difference in power generated by a particular generator (P_i) in a certain interval and that of in the previous interval P_{i0} must not exceed by more than a certain amount called the up-ramp rate limit URi and must not decrease by less than certain amount called the downramp rate limit DRi of that generator.

These constraints are given as

As generation increases $P_i - P_{i0} \leq UR_i$

As generation decreases $P_{i0} - P_i \leq DR_i$ and

$\max(P_{i\,min}, P_{i0} - DR_i) \leq P_i \leq \min(P_{i\,max}, P_{i0} + UR_i)$.(11)



Ramp Rate Limits

2.6 Prohibited Operating Zones

In some operating Zones, the efficiency of the machine falls below the acceptable level, so the units are not put into operation in those ranges or zones. These zones are called Prohibited operating zones. There can be multiple such zones for any machine, which makes the problem of ELD still more complex. For unit i with POZs, the feasible operating zones can be described as follows:

$P_{i\,min} <= P_i <= P_{l\,i,1}$

$P_{u\,i,j-1} <= P_i <= P_{l\,i,j}$ $\quad j=2,3,\ldots\ldots.ni$

$P_{l\,i,ni} <= P_i <= P_{i\,max}$ (12)

Where

j is the number of prohibited operating zone of unit i.

$P_{li,j}$ is the lower limit of jth prohibited operating zone and

$P_{ui,j-1}$ is the upper limit of (j-1)th prohibited operating zone of ith unit.

ni is the total number of POZs of ith unit.

2.7 The Objective Function

The objective function is to minimize the total cost (fuel cost and operating operating cost) of all the Thermal power generating units connected to the system by strategically scheduling the load among them.

$Cost_{total} = \sum_{i=1}^{n}(C_i P_i)$.(14)

The Equation (14) is evaluated considering the fuel cost co-efficients, valve point loading effects, penalty due to emissions and minimum and maximum loading capacities, transmission line losses at various loads, ramp rates, POZ for all the thermal units

2.8 Solver Add-in in Excel

Excel Solver is a What-if Analysis Tool which has a special set of commands to support. It is primarily used in various business and engineering models for the purpose of simulation and optimization. It is helpful where the best decision is needed when dealing with various types of optimization problems. It is used to find the optimal value i.e., the most economical value of cost function such that the load scheduling meets the load demand. The Excel solver algorithm used is GRG non linear Algorithm and Evolutionary Algorithm applicable for non-smooth and most difficult type of optimization problems.

The various solver parameters like cost coefficients, emission coefficients, different load demands, transmission losses and the constraints like minimum, maximum values, limits of ramp rate for either increase or decrease in the scheduled generation, prohibited operating zones of thermal power plants are placed in a spreadsheet. The optimum(minimum) value of cost is set as the objective function of the system, the load scheduling for various units will be the changing variable cells which in turn is equal to the sum of allocated load demand and transmission losses at that particular load. The cost of power plants are subjected to the constraints which can be defined in the algorithm. The GRG Nonlinear Algorithm in solver is used to solve ELD and arrives at a locally optimal solution and also globally optimal solution. GRG means “Generalized Reduced Gradient”. In this method, the gradient or slope of the objective function is taken as the input values or décision variables and are then seperated as basic variables which are dependent variables and non basic variables which are independent variables. In order to obtain optimum value, the reduced gradiant is computed in the search direction till it reaches convergence. It gives the solution at a very fast rate. The Evolutionary method looks at randomness, population, mutation, crossover and selection to solve the problem.

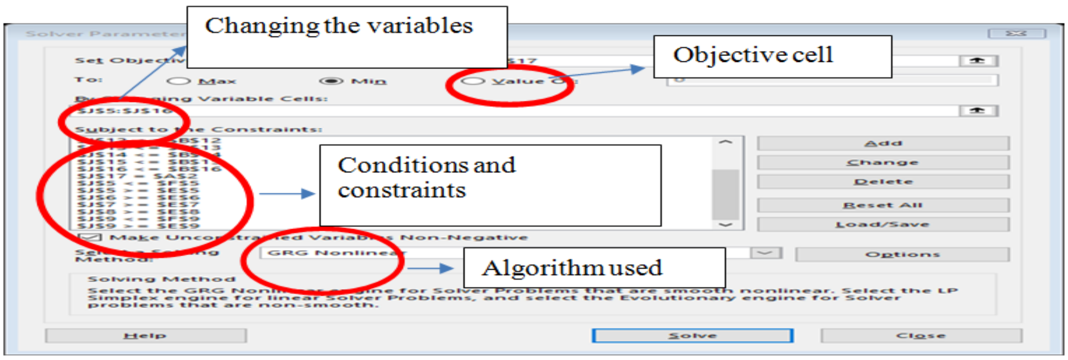


Figure 4: The screen Shot of Solver Configuration.

3. RESULTS AND DISCUSSIONS

The ELD is Conducted on Standard IEEE-30 Bus System.

Table1: The Thermal cost coefficients and Emission coefficients

Thermal Unit	Fuel Cost Co-Efficients			P G min MW	P G max MW	αi (Kg/MW²hr)	βi (Kg/MWhr)	γi (Kg/hr)
	a	b	C					
G1	0.15247	38.539	756.79	10	125	0.00419	0.3267	13.85932
G2	0.10587	46.159	451.32	10	150	0.00419	0.3267	13.85932
G3	0.02803	40.396	1049.99	35	225	0.00683	-0.54551	40.2669
G4	0.03546	38.305	1243.53	35	210	0.00683	-0.54551	40.2669
G5	0.02111	36.327	1658.56	130	325	0.00461	-0.51116	42.89553
G6	0.01799	38.27	1356.65	125	315	0.00461	-0.51116	49.89553

Table 2: Value of Cost Penalty Factor for Emissions at Various Loads

Pmax	hi	hi in ass.order	Corresponding .Pmax	Cumulative .Pmax.	Load	hi
500	4.482696	4.482696	500	500	600	7.287
200	10.45384	7.286594	300	800	800	7.287
300	7.286584	10.45384	200	1000	1000	10.44
150	18.30703	18.30703	150	1150	1200	21.109
200	21.10927	21.10927	200	1350	1263	21.109
120	31.63432	31.63432	120	1470	1400	31.634

Table 3: Ramp Rate Limits And POZ Of The Units

Thermal unit	RRL_L	RRL -U	POZ1[min-max]	POZ2[min—max]
G1	80	120	[210-240]	[350-380]
G2	50	90	[90-110]	[140-160]
G3	65	100	[150-170]	[210-240]
G4	50	90	[80-90]	[110-120]
G5	50	90	[90-110]	[140-150]
G6	50	90	[75-85]	[100-105]

Results of cost of Load dispatch obtained by using GRG Algorithm of Solver with population size 100, number of iterations 100, convergence size:0.00001are given in Table 4.

Table 4: Cost of Load Dispatch using GRG Non linear Algorithm

Load Dispatch and Cost of Load Dispatch using GRG						
Load Demand	**600**	**800**	**1000**	**1200**	**1263**	**1400**
Tr.loss	4.9551	5.0235	8.94075	11.6581	9.4288	11.6581
G1: P_i	209.99	209.99	186.65	209.99	209.99	209.99
cost	3966.114	3966.114	3399.495	7660.049	7659.99	10472.73
G2: P_i	110.00	116.79	177.39	200	180.02	200
cost	2147.259	2293.026	3757.154	7789.753	6708.317	10387.25
G3: P_i	210.68	170	174.89	300	244.75	300
cost	4075.277	2981.112	3102.357	13951.28	9507.533	19122.22
G4: P_i	58.51	80	150	150	150	150
cost	1105.467	1431.543	2869.485	4419.174	4419.174	5599.159
G5: P_i	112.29	154.11	200	200	178.99	200
cost	1817.743	2564.532	3551.338	5280	4447.532	6596.26
G6: P_i	50	75	120	120	120	120
cost	1070.08	1405.375	2138.35	2897.75	2897.75	3475.982
Total P_i	**751.46**	**805.90**	**1008.94**	**1180**	**1180**	**1180**
Total cost	**14181.94**	**14641.7**	**18818.18**	**41998**	**41998**	**55653.61**
Remarks	Could not find a feasible solution where all constraints are met	Could converge at a feasible solution. All constraints are met	All conditions and constraints are satisfied. Solver could find an optimal solution.	Feasibility and feasibility bounds are met	Feasibility and feasibility bounds are met	Feasibility and feasibility bounds are met

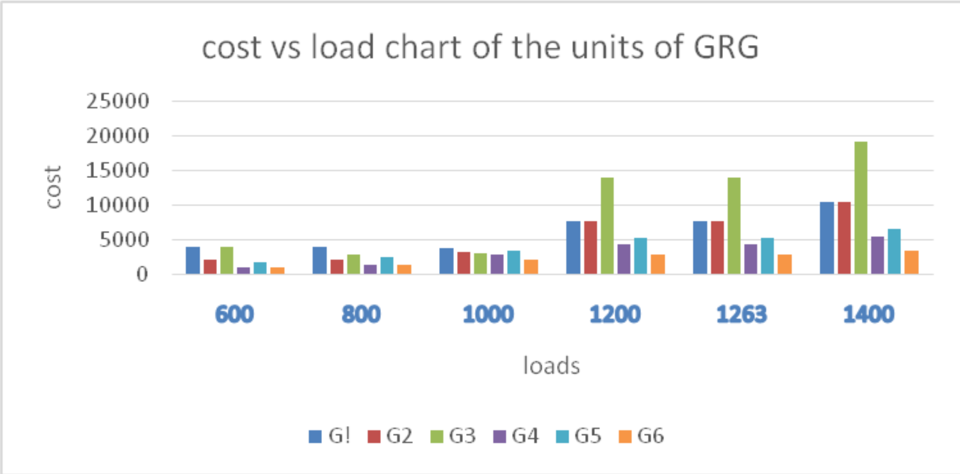


Figure 5: Cost vs Load Chart of the Units.

Results of cost of Load dispatch obtained by using Evolutionary Algorithm of Solver with population size 100, iterations 100, convergence size:0.0001, rate of mutation:0.075, time without change 30secs are given in Table 5.

Table 5: Cost of Load Dispatch using Evolutionary Algorithm

Load Dispatch and Cost of Load Dispatch using Evolutionary Algorithm						
Load Demand	**600**	**800**	**1000**	**1200**	**1263**	**1400**
Tr.loss	3.667681458	6.294985599	8.940752972	1.808348796	2.630692324	1.836410485
G1: P_i	118.2879773	113.6670414	186.6515045	129.9737346	100	100
cost	2327.275694	2224.718797	3399.495418	3951.143708	2876.678392	3807.019392
G2: P_i	53.54209672	127.3001744	177.3991664	90.72989734	50.04243143	53.85366145
cost	1215.800916	2915.94569	3757.154448	2831.866863	1583.382378	2145.321777
G3: P_i	104.3816172	132.6615456	174.8900821	80	80	80
cost	1808.708383	2426.664669	3102.356972	1809.107844	1809.107844	2233.494103
G4: P_i	104.6688295	142.5227584	150	58.79439897	59.03052125	105.2425816
cost	2056.010258	3008.682871	2869.48492	1549.204085	1553.343939	3307.868909
G5: P_i	133.7816887	177.5170692	200	54.47442888	88.59772905	50
cost	2363.740181	3354.146683	3551.337943	1422.198711	1926.447209	1677.921824
G6: P_i	89.00497695	112.6258539	120	64.65257798	97.30240038	90.39148905
cost	1745.084107	2167.52161	2138.350185	1759.590751	2353.324235	2644.117803
Total P_i	**603.6671863**	**806.2944429**	**1008.940753**	**478.6250377**	**474.9730821**	**479.4877321**
Total cost	**11516.61954**	**16097.68032**	**18818.17989**	**13323.11196**	**12102.284**	**15815.74381**
Remarks	All constraints are satisfied	All conditions and constraints are satisfied	All conditions and constraints are satisfied. Solver could find a better solution than existing one.	Feasibility and feasibility bounds are not met	Feasibility and feasibility bounds are met	Feasibility is met but could not get find an optimal sol within the given time

Table 6: Comparison between GRG Nonlinear and Evolutionary Algorithms

Load/ Algorithm	GRG			Evolutionary		
	TL	Load	Cost	TL	Load	Cost
600	4.95	751.46	14182	3.66	603.66	11516
800	5.02	805.9	14641	6.29	806.29	16097
1000	8.94	1008.54	18818	8.94	1008.94	18818
1200	11.66	1180	41998	1.81	478.62	13323
1263	9.43	1180	41998	2.63	474.97	12102
1400	11.66	1180	55654	1.84	479.49	15815

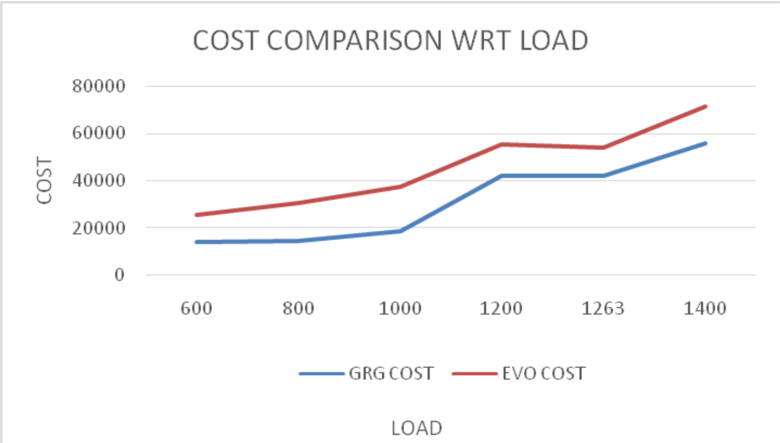


Table 6: Cost Comparison Chart.

4. CONCLUSIONS

The ELD on six thermal power generating units connected to IEEE-30 bus system is calculated using GRG Non-linear algorithm and Evolutionary algorithm in solver and found that GRG nonlinear algorithm gives better and quicker results at all loads compared to Evolutionary engine in a given time. The results in Evolutionary algorithm may improve if more iterations are done which consumes more time to arrive at a feasible solution satisfying all the conditions and constraints.

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